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QUARTERLY REPORT

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Characterization and Fitness for Service of Corroded Cast Iron Pipe

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Prepared For:

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety
Chris McLaren
281-216-4455
Chris.mclaren@dot.gov

Technical Team:

Project Manager:
Kristine Wiley - GTI
(847) 768-0910
kristine.wiley@gastechnology.org

Technical Contact:
Daniel Ersoy - GTI
R&D Executive Director, Infrastructure
(847) 768-0663
daniel.ersoy@gastechnology.org

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

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Project Objective

Gas Technology Institute's (GTI) objective in this project is to

- Provide a Fitness-For-Service (FFS) model and method for operators to characterize and grade graphitic corrosion defects on cast iron natural gas pipes. This will help operators make monitoring, repair, and replacement decisions, as well as prioritize accelerated replacement decisions related to cast iron mains and services.
- Summarize and categorize the required input parameters to the FFS model related to cast iron material, graphitic corrosion geometry and characteristics, and operational environment.
- Validate the FFS model by comparing its output to a statistically analyzed set of historical cast iron failure data.
- Provide a physical testing program to fully validate the FFS model.

Executive Summary

During this quarter, efforts were focused on Task 3 and Task 4. In Task 3 Historical Cast Iron Failures Statistical Analysis, we completed a review of the cast iron distribution system and its properties as well as defamations and stresses on cast iron pipes due to soil and external loads. The review of cast iron reported incidents and characteristics is still in progress. In Task 4 Finite Element Analysis of Failure Modes, we completed the FEA Design Document which summarizes the finite element analysis (FEA) approach taken for this project. This is the first of 2 deliverables under Task 4 of the project.

In Task 5 we continued to collect references and data to help operators characterize graphitic corrosion in the field in a manner that will allow input to the fitness for service model.

A peer review for the project was also conducted on May 25th and the presentation is available on PHMSA's project site.

Work Completed this Quarter (4/1/16 – 6/30/16)

Work Completed

Task 3. Historical Cast Iron Failures Statistical Analysis – We have completed a review of the cast iron distribution system and its properties as well as defamations and stresses on cast iron pipes due to soil and external loads. Review of cast iron reported incidents and characteristics is still in progress.

Task 4. Finite Element Analysis of Failure Modes – We completed the Task 4 Interim Report, FEA Design Document which summarizes the finite element analysis (FEA) approach taken for this project. This is the first of 2 deliverables under Task 4 of the project.

Task 5. Characterize Graphitic Corrosion Severity - We are continuing to collect references and data to characterize graphitic corrosion in the field in a manner that will allow input to the fitness for service model.

Technical Status

Activity: Task 3 - Historical Cast Iron Failures Statistical Analysis

Work on Task 3 covered the following sections:

a) Review of the cast iron distribution system and its properties,

b) Defamations and stresses on cast iron pipes due to soil and external loads,

c) Review of cast iron reported incidents and characteristics.

The reviews of sections (a) and (b) are complete and work is in progress for section (c). This task is expected to be completed as scheduled on September 30, 2016. An interim report of Task 3 is due in the 3rd quarter of 2016.

Review of Cast Iron Incidents [2010-2016]

The review is being performed on the incidents that occurred in the gas distribution system and reported to PHMSA. Incidents are categorized by pipeline type, size, causes of failure, and other metrics. The review also investigates the NTSB reports on the incidents related to cast iron pipe failures. Table 1 and Table 2 show a list of the PHMSA reported incidents of the cast iron failures from 2010 to 2016. Table 1 provides the system properties and Table 2 shows the causes and failure and characteristics [1].

The data incidents in the tables present the serious incidents (i.e., causing fatality or injury) and significant incidents which result in fatality, injury, $50,000 or more in total costs, or volatile gas or liquid release.

Figure 1 shows the number of incidents from 2010 to 2016 sorted by material type. Incidents of cast iron and wrought iron pipes were 34 out of the total of 660 incidents in this five-year period. The reported cast iron incidents represented about 5% of all the pipe type accidents as shown in Figure 1. This ratio is higher than the cast iron mileage in the gas distribution mains of about 2.3% [2]. Figure 2 shows that the cast iron incidents resulted in leaks in about 50% of the incidents. Pipe ruptures occurred in 6 pipes and the others were mostly characterized by circular cracking due to external loads.

Table 1. Cast Iron Pipes and System Characteristics in Reported Incidents [2010-2016]

YEAR	CITY_NAME	STATE	FATALITY_	INJURY_IN	INJURE	SHUTDOWN_	IGNITE_IND	EXPLODE_IND	INCIDENT_AREA_SUBTYPE	DEPTH_OF COVER	CROSSING	SYSTEM_PART_INV	INSTALLATION_	PIPE_DIAMETER	LEAK_TYPE
2016	DETROIT	MI	NO	NO	0	NO	YES	YES	INSIDE A BUILDING		NO	MAIN	1931	6	CRACK
2015	NEW YORK	NY	NO	NO	0	YES	YES	NO	UNDER PAVEMENT	33	NO	MAIN	1907	6	
2015	SAINT LOUIS	MO	NO	NO	0	YES	NO	NO	UNDER PAVEMENT	43	NO	MAIN	1902	16	CRACK
2015	DETROIT	MI	NO	YES	1	NO	YES	YES	INSIDE A BUILDING		NO	MAIN	1923	6	CRACK
2015	NORTHBORO	MA	NO	NO	0	NO	YES	YES	INSIDE A BUILDING		NO	MAIN	1929	6	CRACK
2015	PHILADELPHIA	PA	NO	NO	0	NO	YES	YES	UNDER PAVEMENT	30	NO	MAIN	1906	6	CRACK
2015	JACKSON	MI	NO	YES	1	NO	NO	NO	UNDER PAVEMENT	42	NO	MAIN	1932	4	CRACK
2015	CORDOVA	AL	YES	YES	3	YES	YES	YES	UNDER SOIL	60	NO	MAIN	1952	6	
2014	SAINT LOUIS	MO	NO	NO	0	NO	NO	NO	UNDER PAVEMENT	62	NO	MAIN		8	
2014	CHICAGO	IL	NO	NO	0	YES	NO	NO	EXPOSED DUE TO EXCAVATION	60	YES	MAIN	1962	20	CONNECTION FA
2014	PHILADELPHIA	PA	NO	YES	1	YES	YES	YES	UNDER PAVEMENT		NO	MAIN	1939	4	
2014	BROOKLYN	NY	NO	YES	3	NO	YES	YES	INSIDE A BUILDING		NO	MAIN	1926	4	CRACK
2013	BIRMINGHAM	AL	YES	YES	1	NO	YES	YES	UNDER SOIL	36	NO	MAIN	1951	2.25	CRACK
2013	COLUMBUS	OH	NO	YES	1	NO	YES	NO	EXPOSED DUE TO EXCAVATION	36	NO	MAIN		4	OTHER
2013	PITTSBURGH	PA	NO	NO	0	NO	NO	NO	VAULT	36	NO	VALVE 12 INCH	1959		CRACK
2013	FITCHBURG	MA	NO	NO	0	YES	NO	YES	UNDER SOIL	28	NO	MAIN		4	CRACK
2013	JACKSON	MO	NO	NO	0	YES	NO	NO	ABOVEGROUND		NO	REGULATOR/METER	1980		
2012	SAINT LOUIS	MO	NO	NO	0	YES	YES	NO	EXPOSED DUE TO EXCAVATION	48	NO	MAIN	1961	12	
2012	BALTIMORE	MD	NO	NO	0	YES	NO	NO	EXPOSED DUE TO EXCAVATION	38	NO	MAIN	1909	4	
2012	AUSTIN	TX	YES	YES	1	YES	YES	YES	UNDER SOIL	38	NO	MAIN	1950	4	
2011	BALTIMORE	MD	NO	NO	0	YES	NO	NO	EXPOSED DUE TO EXCAVATION		NO	MAIN	1900	12	
2011	DETROIT	MI	YES	NO	0	NO	NO	NO	UNDER SOIL	54	NO	MAIN	1928	6	
2011	BALTIMORE	MD	NO	NO	0	YES	YES	NO	ABOVEGROUND		NO	OUTSIDE METER/RE	2010		
2011	BALTIMORE	MD	NO	NO	0	NO	YES	NO	ABOVEGROUND		NO	OUTSIDE METER/RE	1980		
2011	DETROIT	MI	NO	NO	0	NO	NO	YES	INSIDE A BUILDING		NO	MAIN	1930	4	CRACK
2011	READING	PA	YES	YES	3	YES	YES	YES	UNDER PAVEMENT	52	NO	MAIN	1928	12	CRACK
2011	BALTIMORE	MD	NO	NO	0	YES	YES	NO	ABOVEGROUND		NO	OUTSIDE METER/RE	2000		
2011	SALISBURY	MD	NO	NO	0	NO	YES	NO	ABOVEGROUND		NO	SERVICE RISER	2003		
2011	PHILADELPHIA	PA	YES	YES	3	YES	YES	YES	UNDER PAVEMENT	37	NO	MAIN	1942	12.75	CRACK
2010	ATLANTA	GA	NO	NO	0	YES	NO	NO	UNDER PAVEMENT	48	YES	MAIN	1924	4	
2010	MOBILE	AL	NO	YES	1	NO	NO	NO	VAULT		NO	OTHER	1950		
2010	DENVER	CO	NO	NO	0	YES	YES	YES	UNDER SOIL	18	NO	SERVICE	1940	1.25	
2010	WALTHAM	MA	NO	YES	1	NO	YES	YES	UNDER SOIL	48	NO	MAIN	1930	6	CRACK
2010	NEWARK	NJ	NO	NO	0	NO	YES	YES	INSIDE A BUILDING		NO	MAIN	1959	16	

Table 2. Cast Iron Causes of Failure Characteristics in Reported Incidents [2010-2016]

YEAR	CITY_NAME	STATE	CLASS_LOCATION_T	NORMAL_PSIG	MOP_PSIG	CAUSE	CORROSION_TYP	NATURAL_FORCE_TYPE	NF_EXTREME_WEATHER_DETAI	EX_PARTY_TYPE	OUTSIDE_FORCE_TYPE
2016	DETROIT	MI	CLASS 3 LOCATION	5	5	MATERIAL FAILURE OF PIPE OR WELD					
2015	NEW YORK	NY	CLASS 4 LOCATION	0.25	0.5	OTHER INCIDENT CAUSE					
2015	SAINT LOUIS	MO	CLASS 3 LOCATION	23	25	OTHER INCIDENT CAUSE					
2015	DETROIT	MI	CLASS 3 LOCATION	2	2	NATURAL FORCE DAMAGE		TEMPERATURE			
2015	NORTHBORO	MA	CLASS 3 LOCATION	0.34	0.5	NATURAL FORCE DAMAGE		TEMPERATURE	PIPE WAS IN FROZEN GROUND.		
2015	PHILADELPHIA	PA	CLASS 4 LOCATION	0.25	0.5	NATURAL FORCE DAMAGE		TEMPERATURE			
2015	JACKSON	MI	CLASS 3 LOCATION	0.5	0.97	NATURAL FORCE DAMAGE		TEMPERATURE			
2015	CORDOVA	AL	CLASS 1 LOCATION	22	40	NATURAL FORCE DAMAGE		EARTH MOVEMENT			
2014	SAINT LOUIS	MO	CLASS 3 LOCATION	1.1	2.2	EXCAVATION DAMAGE				EXCAVATION DAMAGE	
2014	CHICAGO	IL	CLASS 4 LOCATION	22	25	INCORRECT OPERATION					
2014	PHILADELPHIA	PA	CLASS 4 LOCATION	0.25	0.5	NATURAL FORCE DAMAGE		TEMPERATURE			
2014	BROOKLYN	NY	CLASS 4 LOCATION	0.33	0.65	OTHER INCIDENT CAUSE					
2013	BIRMINGHAM	AL	CLASS 3 LOCATION	19	25	OTHER INCIDENT CAUSE					
2013	COLUMBUS	OH	CLASS 3 LOCATION	0.45	1	OTHER INCIDENT CAUSE					
2013	PITTSBURGH	PA	CLASS 3 LOCATION	143	150	INCORRECT OPERATION					
2013	FITCHBURG	MA	CLASS 3 LOCATION	0.5	0.5	NATURAL FORCE DAMAGE		EARTH MOVEMENT			
2013	JACKSON	MO	CLASS 3 LOCATION	70	80	EQUIPMENT FAILURE					
2012	SAINT LOUIS	MO	CLASS 3 LOCATION	12.5	25	CORROSION FAILURE	GRAPHITIC				
2012	BALTIMORE	MD	CLASS 2 LOCATION	0.28	0.36	EXCAVATION DAMAGE				EXCAVATION DAMAGE	
2012	AUSTIN	TX	CLASS 3 LOCATION	48	60	NATURAL FORCE DAMAGE		OTHER NATURAL FORCE	DROUGHT AND RAINFALL		
2011	BALTIMORE	MD	CLASS 3 LOCATION	0.3	0.36	EXCAVATION DAMAGE				EXCAVATION DAMAGE	
2011	DETROIT	MI	CLASS 3 LOCATION	5	5	CORROSION FAILURE	GRAPHITIZATION				
2011	BALTIMORE	MD	CLASS 4 LOCATION	93	99	OTHER OUTSIDE FORCE DAMAGE					R OTHER FIRE/EXPLOSION
2011	BALTIMORE	MD	CLASS 4 LOCATION	92	99	OTHER OUTSIDE FORCE DAMAGE					OTHER FIRE/EXPLOSION
2011	DETROIT	MI	CLASS 3 LOCATION	5	5	NATURAL FORCE DAMAGE		TEMPERATURE			
2011	READING	PA	CLASS 3 LOCATION	0.36	1	OTHER INCIDENT CAUSE					
2011	BALTIMORE	MD	CLASS 4 LOCATION	85	99	OTHER OUTSIDE FORCE DAMAGE					DAMAGE BY CAR,
2011	SALISBURY	MD	CLASS 3 LOCATION	32	45	OTHER OUTSIDE FORCE DAMAGE					OTHER FIRE/EXPLOSION
2011	PHILADELPHIA	PA	CLASS 4 LOCATION	18	35	MATERIAL FAILURE OF PIPE OR WELD					
2010	ATLANTA	GA	CLASS 3 LOCATION	13	15	EXCAVATION DAMAGE				EXCAVATION DAMAGE	
2010	MOBILE	AL	CLASS 3 LOCATION	40	60	OTHER INCIDENT CAUSE					
2010	DENVER	CO	CLASS 3 LOCATION	5	15	EXCAVATION DAMAGE				EXCAVATION DAMAGE	
2010	WALTHAM	MA	CLASS 3 LOCATION	1.8	2	NATURAL FORCE DAMAGE		TEMPERATURE			
2010	NEWARK	NJ	CLASS 4 LOCATION	32	35	NATURAL FORCE DAMAGE		EARTH MOVEMENT			

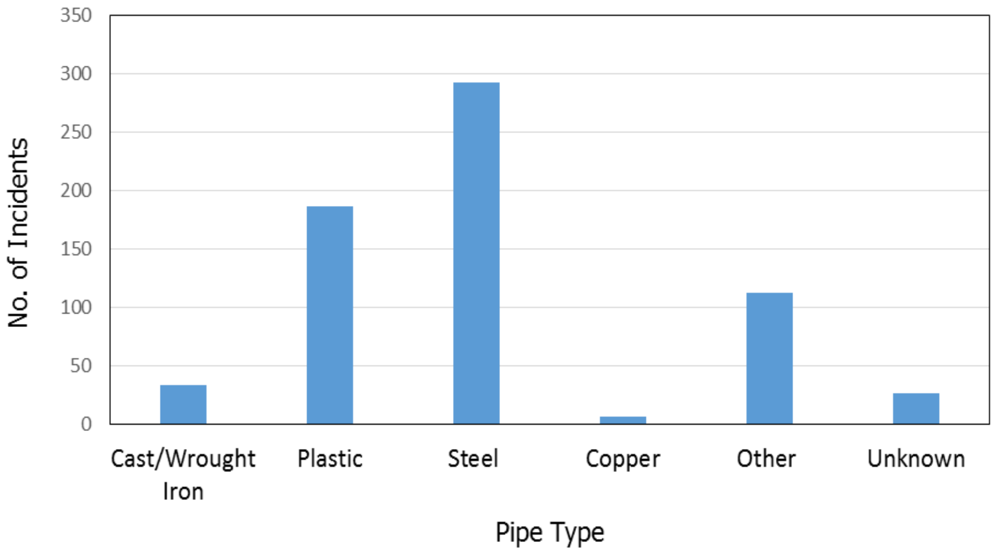

Figure 1. Incidents by pipe material type, from 2010 to present

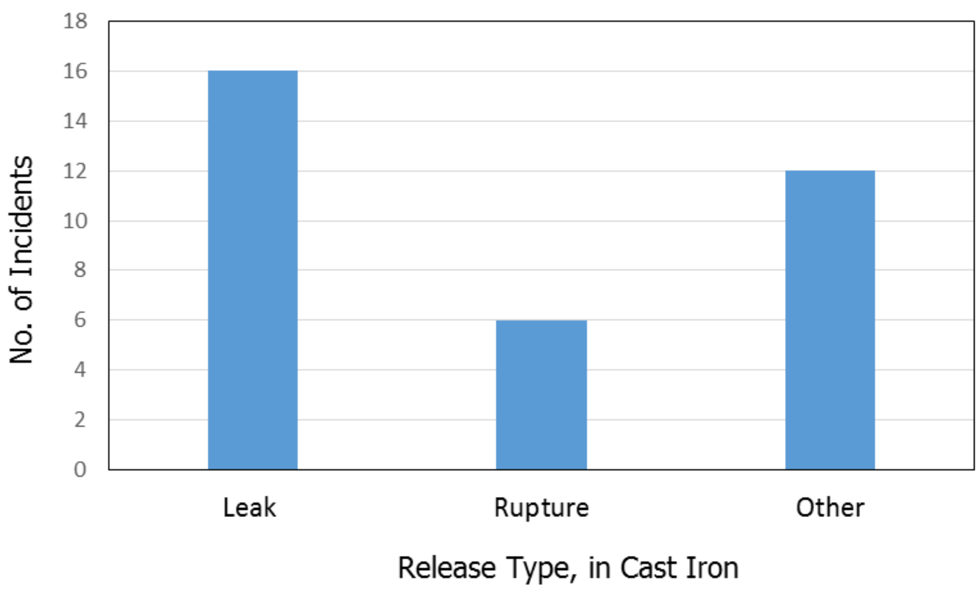

Figure 2. Type of gas release in the cast iron incidents

Figure 3 shows the geographical distribution of the cast iron failure incidents in the U.S., the incidents are categorized by the causes of failure. As shown in Figure 4, out of the 34 incidents in cast iron pipes, two incidents were caused by external corrosion of the pipe.

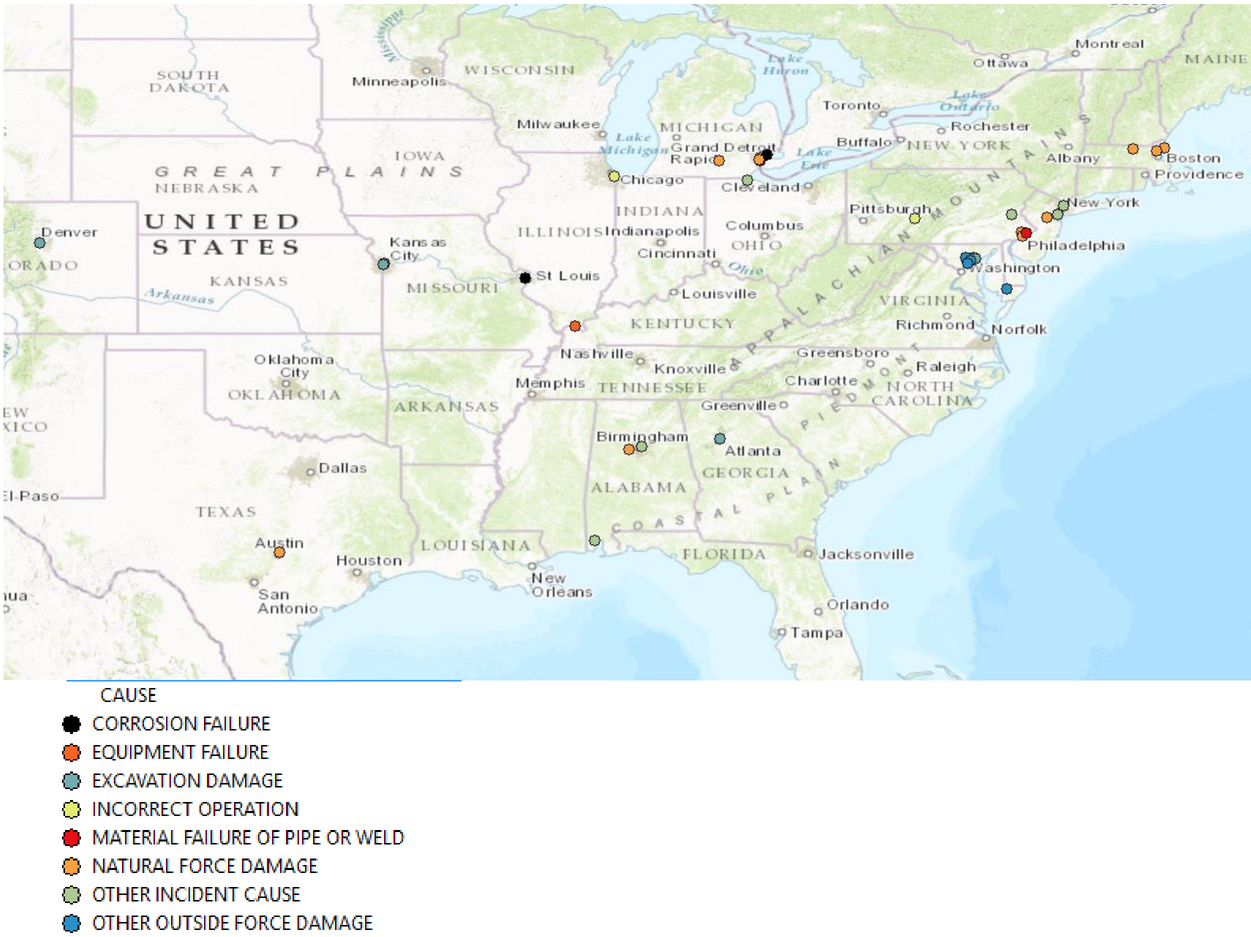

Figure 3. Locations of cast iron incidents [2010-2016]

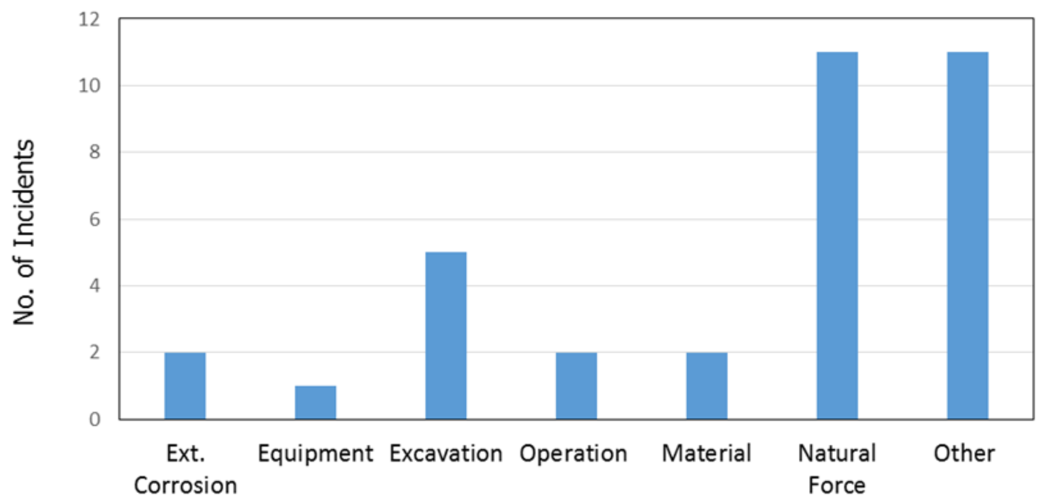

Figure 4. Causes of incidents in cast iron pipes

Task 3 References

1. Pipeline and Hazardous Material Safety administration (PHMSA), Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data, Natural Gas Distribution Incident Data 2010 to present, http://phmsa.dot.gov/pipeline/library/data-stats/flagged-data-files
2. Gas Facts, American Gas Association, https://www.aga.org/annual-statistics

Activity: Task 4 - Finite Element Analysis of Failure Modes

An evaluation of pipe stresses under internal and external loads was conducted and utilized for the FEA design. A summary of this evaluation is provided below.

Pipe Stresses Under Internal and External Loads

A buried natural gas cast iron pipe is commonly subjected to both internal pressure from the pressurized gas and external pressure from the overburden earth load and highway traffic. The pipe may also be subjected to additional loads associated with ground deformations and environmental conditions. The sources of these loads include:

- Shrinking and swelling of soil and frost heave,
- Loss of ground support due to undermining by adjacent excavations,
- Dynamic loads due to earthquakes and nearby blasting,
- Pipe stresses induced by temperature fluctuations.

The pipe may also be subjected to additional initial stresses during installation. These stresses can be caused by carrying and placing the pipe in open trench installation, which was the common installation procedure for cast iron gas mains. However, these initial stresses are not relevant in the purpose of evaluating aged pipes subjected to long-term corrosion.

Stresses Due to Internal Pressure

The internal pressure of the pipe, p (psig) causes circumferential stress on the pipe cross section. The circumferential stress may be calculated using the Barlow formula, $S_{i\,(Barlow)}$ (psi) [1]:

$$S_{i\,(Barlow)} = p\,D/\,2\,t_w \qquad (1)$$

Where,

D Pipe outside diameter, inch

t_w Pipe wall thickness, inch.

Stresses Due to Earth Load

The circumferential pressure due to earth load, P_e (psi) is calculated as follows:

$$P_e = K_e . B_e . E_e . \gamma . D \qquad (2)$$

Where,

K_e Stiffness factor from earth load

B_e Burial factor

E_e Excavation factor

γ Soil unit weight, lb/in³

Values of $K_e, B_e, and\ E_e$ can be obtained from references [2] and [3] as follows:

- The stiffness factor for earth load, K_e accounts for the interaction between the soil and pipe and depends on pipe diameter, wall thickness, and coefficient of soil reaction E_{soil}. The values of E_{soil} ranges from 0.2 ksi for highly plastic, soft to medium silt and clay to 1.0 ksi for very stiff clay and silt. A value of 2 ksi is commonly taken for very dense sands and gravels. Figure 5 shows values of K_e for various soils and pipe parameters.

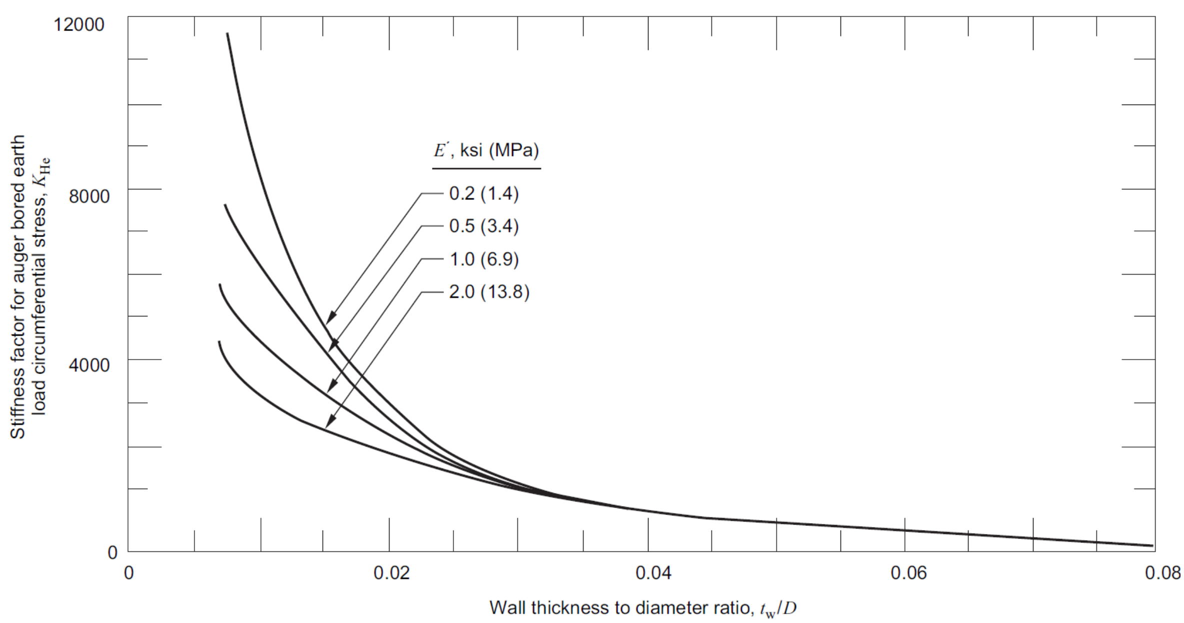

Figure 5. Stiffness factor K_e for stresses due to earth load

- The burial factor B_e depends on the pipe diameter and depth of soil cover. Figure 6 shows the burial factors for various depth of cover H over B_d ratios. For trenched construction, which was the common practice for cast iron pipes installations, the value of B_d equals pipe diameter D.
- The excavation factor E_e is assumed as 1.0 for trenched construction.
- Soil unit weight γ is commonly taken as 120-130 lb/ft³ for most soil types unless higher values are determined in laboratory or field tests.

In general, if the pipe is located below the water table, the vertical earth pressure P_e (psi) is calculated as follows:

$$P_e = \gamma_\omega \,.\, h_\omega + R_\omega \,.\, \gamma_d \,.\, H$$

Where γ_ω is the water unit weight, h_ω is the height of water above pipe, γ_d Dry soil unit weight, and $R_\omega = 1 - 0.33\ (h_\omega/H)$

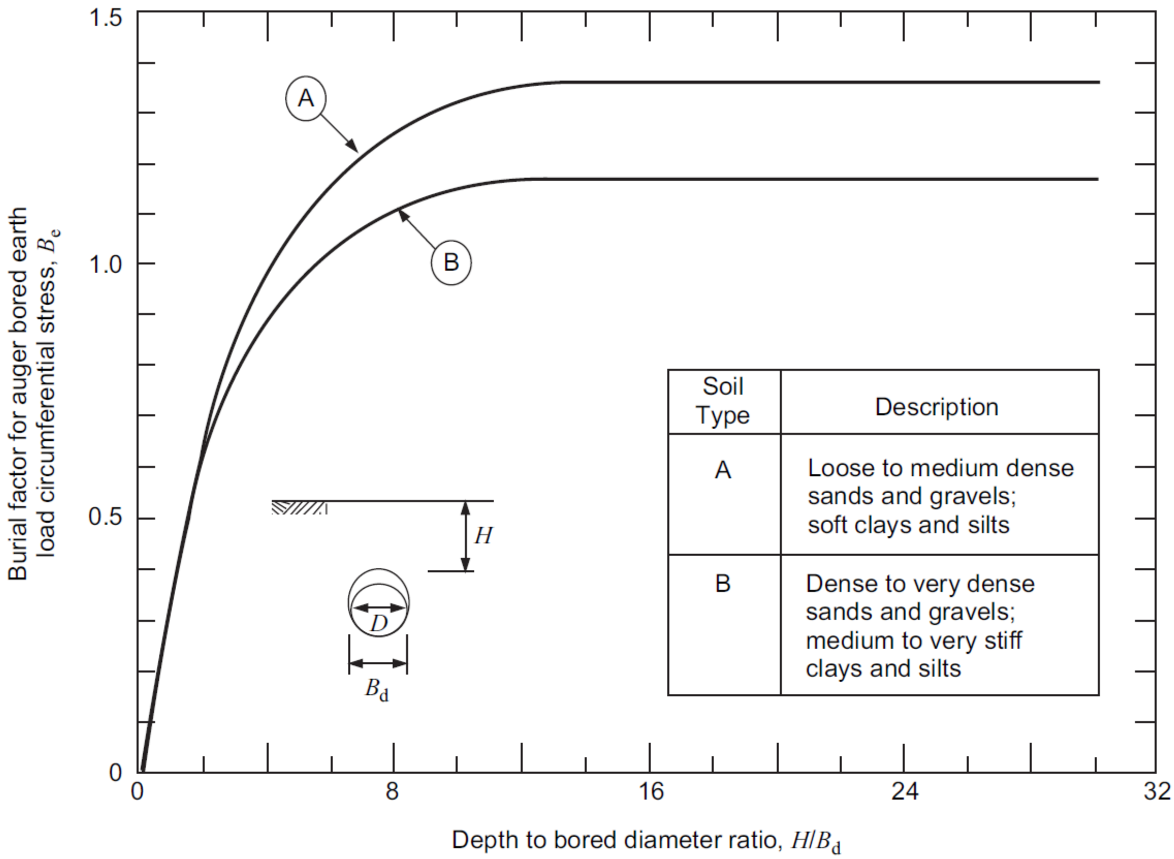

Figure 6. Burial Factor B_e for stresses due to earth load

Stresses Due to Traffic Load

The highway surface pressure w due to the traffic wheel load P at the surface of the roadway is calculated as:

$$w = {}^{P}/_{A_p} \quad (3)$$

Where P is the either the design single wheel load or the design tandem wheel load in lbs. Recommended design load for a single traffic wheel load is 12,000 lb. A_p is the contact area over which the wheel load is applied and it is taken as 144 in^2. For the values above a single axle loading, the surface pressure w = 83.3 psi.

The values in Table 3 show an estimate of the life loads (in psi) with the change of depth of cover for a standard HS-20 truck load at the surface [4].

Live load transferred to pipe, lb/in^2			
Height of cover, ft	Highway H20*	Railway E80†	Airport‡
1	12.50	--	--
2	5.56	26.39	13.14
3	4.17	23.61	12.28
4	2.78	18.40	11.27
5	1.74	16.67	10.09
6	1.39	15.63	8.79
7	1.22	12.15	7.85
8	0.69	11.11	6.93
10	§	7.64	6.09
12	§	5.56	4.76

Table 3. Live loads with depth of cover [4]

Example

- A 6-inch cast iron pipe with internal pressure of 15 psi is buried in 5 ft of soil with dry unit weight of 110 pcf. Water table is at the surface:

For t_w = 0.4 inch

Circumferential stress due to internal pressure = 112.5 psi

Circum. stress due to earth pressure = (62.4 * 5) + (1-0.33) * 110 * 5 = 680 lb/ft^2 = 4.8 psi

Review of Design Codes for Cast Iron Pipes

§ 192.275 Cast iron pipe.

(a) Each caulked bell and spigot joint in cast iron pipe must be sealed with mechanical leak clamps.

(b) Each mechanical joint in cast iron pipe must have a gasket made of a resilient material as the sealing medium. Each gasket must be suitably confined and retained under compression by a separate gland or follower ring.

(c) Cast iron pipe may not be joined by threaded joints.

(d) Cast iron pipe may not be joined by brazing.

§ 192.369 Service lines: Connections to cast iron or ductile iron mains.

(a) Each service line connected to a cast iron or ductile iron main must be connected by a mechanical clamp, by drilling and tapping the main, or by another method meeting the requirements of §192.273.

(b) If a threaded tap is being inserted, the requirements of §192.151 (b) and (c) must also be met.

§ 192.373 Service lines: Cast iron and ductile iron.

(a) Cast or ductile iron pipe less than 6 inches (152 millimeters) in diameter may not be installed for service lines.

(b) If cast iron pipe or ductile iron pipe is installed for use as a service line, the part of the service line which extends through the building wall must be of steel pipe.

(c) A cast iron or ductile iron service line may not be installed in unstable soil or under a building.

§ 192.489 Remedial measures: Cast iron and ductile iron pipelines.

(a) General graphitization. Each segment of cast iron or ductile iron pipe on which general graphitization is found to a degree where a fracture or any leakage might result, must be replaced.

(b) Localized graphitization. Each segment of cast iron or ductile iron pipe on which localized graphitization is found to a degree where any leakage might result, must be replaced or repaired, or sealed by internal sealing methods adequate to prevent or arrest any leakage.

§ 192.557 Uprating:

(d) If records for cast iron or ductile iron pipeline facilities are not complete enough to determine stresses produced by internal pressure, trench loading, rolling loads, beam stresses, and other bending loads, in evaluating the level of safety of the pipeline when operating at the proposed increased pressure, the following procedures must be followed:

(1) In estimating the stresses, if the original laying conditions cannot be ascertained, the operator shall assume that cast iron pipe was supported on blocks with tamped backfill and that ductile iron pipe was laid without blocks with tamped backfill.

(2) Unless the actual maximum cover depth is known, the operator shall measure the actual cover in at least three places where the cover is most likely to be greatest and shall use the greatest cover measured.

(3) Unless the actual nominal wall thickness is known, the operator shall determine the wall thickness by cutting and measuring coupons from at least three separate pipe lengths. The coupons must be cut from pipe lengths in areas where the cover depth is most likely to be the greatest. The average of all measurements taken must be increased by the allowance indicated in the following table:

Pipe size inches (millimeters)	Allowance inches (millimeters)		
	Cast iron pipe		Ductile iron pipe
	Pit cast pipe	Centrifugally cast pipe	
3 to 8 (76 to 203)	0.075 (1.91)	0.065 (1.65)	0.065 (1.65)
10 to 12 (254 to 305)	0.08 (2.03)	0.07 (1.78)	0.07 (1.78)
14 to 24 (356 to 610)	0.08 (2.03)	0.08 (2.03)	0.075 (1.91)
30 to 42 (762 to 1067)	0.09 (2.29)	0.09 (2.29)	0.075 (1.91)
48 (1219)	0.09 (2.29)	0.09 (2.29)	0.08 (2.03)
54 to 60 (1372 to 1524)	0.09 (2.29)		

(4) For cast iron pipe, unless the pipe manufacturing process is known, the operator shall assume that the pipe is pit cast pipe with a bursting tensile strength of 11,000 psi (76 MPa) gage and a modulus of rupture of 31,000 psi (214 MPa) gage.

§ 192.621 Maximum allowable operating pressure: High-pressure distribution systems.

(3) 25 psi gage in segments of cast iron pipe in which there are unreinforced bell and spigot joints.

192.753 Caulked bell and spigot joints.

(a) Each cast iron caulked bell and spigot joint that is subject to pressures of more than 25 psi gage must be sealed with:

(1) A mechanical leak clamp; or

(2) A material or device which:

(i) Does not reduce the flexibility of the joint;

(ii) Permanently bonds, either chemically or mechanically, or both, with the bell and spigot metal surfaces or adjacent pipe metal surfaces; and

(iii) Seals and bonds in a manner that meets the strength, environmental, and chemical compatibility requirements of §§192.53 (a) and (b) and 192.143.

(b) Each cast iron caulked bell and spigot joint that is subject to pressures of 25 psi (172kPa) gage or less and is exposed for any reason must be sealed by a means other than caulking.

§ 192.755 Protecting cast-iron pipelines.

When an operator has knowledge that the support for a segment of a buried cast-iron pipeline is disturbed:

(a) That segment of the pipeline must be protected, as necessary, against damage during the disturbance by:

(1) Vibrations from heavy construction equipment, trains, trucks, buses, or blasting;

(2) Impact forces by vehicles;

(3) Earth movement;

(4) Apparent future excavations near the pipeline; or

(5) Other foreseeable outside forces which may subject that segment of the pipeline to bending stress.

(b) As soon as feasible, appropriate steps must be taken to provide permanent protection for the disturbed segment from damage that might result from external loads, including compliance with applicable requirements of §§192.317(a), 192.319, and 192.361(b)–(d).

References

1. Code of Federal Regulations, CFR Title 49 - Part 192, Transportation of Natural Gas and Other Hazardous liquids by Pipeline, 2008.

2. API, American Petroleum Institute, Steel Pipelines Crossing Railroads and Highways, API Recommended Practice 1102, 2007.
3. Steward, H.E., O'Rourke, T.D., and Ingraffea, A.R., Guidelines for Pipelines Crossing Highways, Cornell University, Report No, GRI-91/0284, Gas Research Institute, December 1991.
4. Guidelines for the Design of Buried Steel Pipe, American Lifelines Alliance, ASCE, July 2001

FEA Design Document

The FEA Design Document is a milestone report that is the first of two deliverables under Task 4 of the project which is performing finite element analysis of cast iron failure modes with graphitic corrosion defect. The report summarizes the finite element analysis (FEA) approach taken for this project.

The FEA simulations will use input parameter value combinations as determined by a design-of-experiment (DoE) methodology. The experiment designs are discussed and parameter value ranges are provided.

A schematic illustration of the boundary conditions and flaw geometry examples are provided. A brief discussion on simulating the non-linear behavior of cast-iron is also included.

Activity: Task 5 - Characterize Graphitic Corrosion Severity

We continued to collect references and data to help operators characterize graphitic corrosion in the field in a manner that will allow input to the fitness for service model.

Activity: Task 10 – Project Management

The Peer Review for this project was held on May 25th. The presentation is available on the PHMSA project site.

Plans for Future Activity (Project Quarter #4)

The planned activities for the 4th Project Quarter are:

- Continue Task 3 work on Historical Cast Iron Failures and Statistical Analysis.
- Continue Task 4 Finite Element Analysis of Failure Modes
- Continue Task 5 Characterize Graphitic Corrosion Severity
- Submit monthly reports